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DTUJET-93**Sampling inelastic proton-proton and antiproton-proton collisions according to the two-component Dual Parton Model**

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Abstract

A new version of a Monte Carlo Program for hadronic multi-particle production is presented. It is based on the two-component Dual Parton Model which includes the dual topological unitarization of soft and hard cross sections. The model treats both soft (low p_{\perp}) and hard (minijet, large p_{\perp}) processes in a unified and consistent way. The unified description is important at TeV-energies of hadron colliders, where the hard perturbative cross sections of QCD become large and comparable to the total cross sections.

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1. Program Summary

Title of program:	DTUJET
Catalog number:	
Program obtainable	from CPC Program Library, Queen's University of Belfast, N. Ireland (see application form in this issue)
Computer on which the program has been thoroughly tested:	RISC-Workstations: DEC, HP, and IBM
Operating system:	UNIX-systems: DEC-ULTRIX, HP-UX and IBM-AIX
Programming language used:	FORTRAN-77
Memory required to execute with typical data using the DOUBLE PRECISION options	11.5 megabyte
No. of bits in a word	64
Has the code been vectorized?	no
Number of lines in distributed program:	45000 (including data files)
Other programs used in DTUJET in modified form	BAMJET ^[1] Sampling the hadronization of strings. DECAY ^[2] Sampling the decay of hadron resonances. JETSET ^[3] Sampling the decay of strings. RNDM Processor independent random number generator.

Keywords:	Monte Carlo event generator, hadron-hadron scattering, fragmentation, hadronic final states.
Nature of physical problem:	Simulation of high energy hadron collisions.
Method of solution:	Monte Carlo generation of individual events which step by step follows the evolution of the scattering process postulated in the Dual Parton Model.
Restrictions on the complexity of the problem	Above 40 TeV arrays have to be enlarged. No tests were done below $\sqrt{s} = 50$ GeV.
Typical running time:	100 thousand events at an energy of 40 TeV require a DEC-station 5260 running time of 33 minutes, of which about 30 seconds are used for initialization.

2. Dual Unitarization of Soft and Hard Hadronic Interactions

The dual topological unitarization of hard and soft hadronic cross sections is the basis for our model of hadronic multi-particle production. First descriptions of the model were given in [4–6]. The physics of the former version of the code, DTUJET–90, which is largely unchanged, was described in the papers [7,8]. The program follows the evolution of the scattering process step by step in a probabilistic way. It maintains energy, momentum and flavor conservation with an relative accuracy of better than 10^{-4} .

New in the code DTUJET–93 is the use of modern parton structure functions for calculating the minijet component, new fits to total, elastic, inelastic, and single diffractive cross sections, a careful treatment of the low-mass and high-mass single diffractive component^[9,10,11] and the introduction of sea diquarks and other improvements in order to get a updated description of strange particle production in the Dual Parton Model^[14].

Soft hadronic multi-particle production in the framework of the Dual Parton Model^[15] was studied by several groups^[16–20]. These studies and in particular the Monte-Carlo-formulation of the model in the form of a dual multi-chain fragmentation model^[19,20] were the first starting point of DTUJET model.

Experimental observations at collider energies made it clear that the soft and hard components of hadronic multi-particle production are closely related. We refer to the discovery of correlations between the average transverse momentum of produced hadrons and the multiplicity density in the central rapidity range^[21]. This property could be understood within the dual multi-chain fragmentation model^[20,22] only by introducing transverse momenta at the ends of the fragmenting strings. The magnitudes of some of the transverse momenta needed in this way could only be interpreted as due to hard constituent scattering.

The need for a uniform treatment of hard and soft hadronic multi-particle production is furthermore underlined by the fact that the perturbative QCD cross section for hard constituent scattering rises strongly with the energy. It reaches values larger than the total hadronic cross section at the energies of proposed supercolliders. At these energies one expects that unitarity corrections should play an important role. Those corrections then inevitably lead to several semi-hard interactions resulting in an increase of the average number of jets.

The perturbative hard constituent scattering is one of the processes responsible for the rise of the hadronic cross sections. This was studied quantitatively in papers by Capella, Tran Thanh Van and Kwiecinski^[23] and by Durand and Pi^[24], where the consequences for the total and inelastic cross sections of the unitarization of soft and hard scattering cross sections were studied. This model in the form as formulated in [23] is the second starting point of the DTUJET-model.

For more details about the model we refer to the papers [5-14] .

3. Description of DTUJET-93

3.1. THE STRUCTURE OF DTUJET-93

The DTUJET source code consists of several FORTRAN files. The user will need the following ones:

- `dtu93mai`: contains the routines which organize the various tasks to be performed. The central part, the main program DTMAIN, will be described in the next section.
- `dtu93col`: collects actual events utilizing the following files. Contains call to default and dummy histograming routines.
- `dtu93pom`: contains routines to calculate the multi-Pomeron distributions, sample from these distributions, and calculate the total and inelastic cross sections.
- `dtu93par`: formulates the model on the parton level, samples the strings and the partons at the ends of the strings.
- `dtu93diq`: contains the routines for sampling sea-sea chains with sea-diquarks besides sea-quarks at the ends.
- `dtu93sof`: contains the routines for sampling the soft parton distributions by an alternative method.
- `dtu93lap`: contains the routines used to sample the hard scattering of constituents.
- `dtu93tcb`: contains the BAMJET^[1] and DECAY^[2] routines for string fragmentation and routines to test and call BAMJET.
- `dtu93lun`: contains a short interface to the JETSET^[3] program.
- `dtu93luj`: A copy of JETSET version 7.3 (converted to allow for compilation under DOUBLE PRECISION) is included for the convenience of the user.
- `dtu93dif`: contains the routines for sampling diffractive chains.
- `dtu93his`: contains standard histograming routines.
- `dtu93lib`: contains general purpose library routines.

On the UNIX-machines these files have the extension `.f`. In addition, data files `struf90.dat` and `struf93.dat` will be required by a routine in `dtu93lap`. These files contain tables which allow to calculate structure functions parametrized in various ways.

Most parts of the program, for instance the

- sampling of multi-Pomeron events,
- hadron structure functions,
- hard perturbative constituent scattering cross sections,
- the method of string fragmentation into hadrons, and
- the method of selecting the exclusive parton events (x -values and flavors),

are programmed as distinct entities, which can in principle be exchanged by suitable other codes. For some of these tasks DTUJET-93 offers several options; for others this is foreseen and easy to implement.

3.2. THE MAIN PROGRAM

The main program DTMAIN is provided to allow for a stand-alone running of the program. It is unnecessary for a user who wants to call the event generator from its own programs.

It contains the following lines

```
PROGRAM DTMAIN
1  CALL DTPREP(NEVNT)
   DO 9 I=1,NEVNT
9   CALL DTCOLL
   CALL DTHIST
   GOTO 1
END
```

which are largely self explanatory.

To prepare the generator a call to DTPREP is necessary. It initializes variables in a way chosen by the user and allows for preparatory tasks. Its actions are controlled by input cards. Each input card is identified by a code word which specifies its function as described in the next section. Without specification default values are taken. The subroutine is left if the code word START is encountered. Please note, that the nature of these initializations makes it for many tasks impossible to create events, which need a different initialization during one run of the code. A good praxis is therefore, to have a separate run of the code for each problem to be solved.

A call to the subroutine DTCOLL generates one event. The event is stored in a COMMON block /USER/ and /PARTCL/ as described in section 4.

To check the generated events, a call to the subroutine DTHIST provides short histogram output, which was prepared in DTPREP and DTCOLL without action of the user. It contains a call to a dummy routine DTHSTO(I), which can be replaced by a histograming routine supplied by the user. It is called at the beginning with the argument $I = 1$ for initialization and preparatory work, with the argument $I = 2$ each time a new event has been generated to allow summations needed for the calculation of expectation values and with the argument $I = 3$ after all the desired events have been generated for normalizations and print outs.

3.3. INPUT CARDS AND OPTIONS

The subroutine DTPREP uses input cards. All input cards of DTUJET have the following form:

```
CODEWD, (WHAT(I), I = 1,6), SDUM
FORMAT ( A8, 2X, 6E 10.0, A8)
```

The initial code word, which is read in as CODEWD, determines the meaning of the remaining variables, as described in the following.

Code word: TITLE

Parameter used: none

This card must be followed by a card giving the title of the run, which will be reproduced in the output.

Code word: COMMENT

Parameter used: NCOM = WHAT(1)

This card allows one to add NCOM comment lines. It must be followed by NCOM comment cards, which will be reproduced in the output.

The default is NCOM = 1.

Code word: CMENERGY

Parameter used: ECM = WHAT(1)

This card defines the center of mass energy ECM of the collision in GeV.

The default is ECM = 1800 GeV.

Code word: PROJPAR

Parameter used: PROJTY = SDUM

Defines the projectile particle type, defined to move into positive z -direction.

The possible values are: PROTON, APROTON

The default is PROTON

Code word: TARPAP

Parameter used: TARGTY = SDUM

Defines the target particle type, defined to move into negative z -direction.

The possible values are: PROTON

The default is PROTON

Code word: SINGDIFF

Parameters used:

ISINGD = WHAT(1), IDUBLD = WHAT(2), SDFRAC = WHAT(3)

Calls or suppresses diffractive events.

ISINGD

- = 0 : Single diffraction suppressed.
- = 1 : Single diffraction included to a fraction given by third parameter.

IDUBLD

- = 0 : Double diffraction included.
- = 1 : Only double diffractive events.

SDFRAC

- = 0 .. 1 : Fraction of single diffractive events to be included in inelastic events. The value 1 (0.05) means that all (5%) of the single diffractive events are included.

The defaults are ISINGD = 0, IDUBLD = 0, SDFRAC = 0 .

Code word: STRUCFUN

Parameter used: ISTRUF = WHAT(1)

Defines the structure functions used in the sampling of hard constituent scattering^[25,26,27,28].

ISTRUF	= 3 :	Martin, Roberts, Stirling: Set 1
	= 9 :	Kwiecinski,Martin, Roberts, Stirling: Set B0
	= 10 :	Kwiecinski,Martin, Roberts, Stirling: Set B ₋
	= 11 :	Kwiecinski,Martin, Roberts, Stirling: Set B ₋₂
	= 12 :	Kwiecinski,Martin, Roberts, Stirling: Set B ₋₅
	= 13 :	Martin, Roberts, Stirling (1992): Set S0
	= 14 :	Martin, Roberts, Stirling (1992): Set D0
	= 15 :	Martin, Roberts, Stirling (1992): Set D ₋
	= 16 :	CTEQ Collaboration (1993): Set 1M
	= 17 :	CTEQ Collaboration (1993): Set 1MS
	= 18 :	CTEQ Collaboration (1993): Set 1ML
	= 19 :	CTEQ Collaboration (1993): Set 1D
	= 20 :	CTEQ Collaboration (1993): Set 1L
	= 210 .. 220 :	as above with energy dependent p_{\perp} threshold value

The default is 215 .

The fits include functions with conventional $1/x$ singularity of sea-quarks and gluon distributions (for instance the MRS[D0] functions) as well as functions with a $1/x^{1.5}$ singularity (for instance the MRS[D₋] functions) with and without shadowing.

The hard process contributes above a p_{\perp} threshold. The threshold is set for less than three digits ISTRUF values to 3 GeV by default. This option was used in the earlier DTUJET-92 version of the program. An energy dependent cutoff^[29,29] can avoid a hard scattering cross section too large to be treated in our simple eikonal approximation. To use this new option the number 200 has to be added to the chosen ISTRUF value.

Code word: SEASU3

Parameters used: SEASQ = WHAT(1)

This card concerns the fraction of strange quarks at the end of sea-chains.

SEASQ	= 0.33 :	gives at the ends of sea chains the same strangeness suppression as inside the chain decay.
	= 1.0 :	demands equal fractions of u, d and s sea quarks at the ends of sea-chains.

The default is 1.

Code word: HADRONIZ

Parameters used: IHADRZ = WHAT(1)

This card defines the fragmentation program used.

IHADRZ	= 1 :	uses the BAMJET and DECAY programs.
	= 2 :	uses the program JETSET version 7.3 .

The default is 2.

Most of our calculations used the BAMJET option. The calculations in [12,29] were done with the JETSET option, which allowed to include hard parton showers (see PSHOWER code word).

The internal parameters of these programs are described in the referenced papers^{[1][3]}. DTUJET-93 uses for some JETSET parameters non-default values (see DTU93LUN.f file), DTUJET-93 also applies non-default values for some BAMJET parameters (see DTU93TCB.f file).

Code word: POPCORN

Parameters used: PDB=WHAT(1)

This card determines the role of diquarks in the fragmentation.

PDB (with BAMJET)		
	= 0 .. 1 :	gives the fraction of diquarks fragmenting in the directly into baryons.

PDB (with JETSET)		
	= 0 :	The POPCORN mechanism is switched off.
	> 0 :	The POPCORN mechanism is switched on.

The default is 0.5.

Code word: PSHOWER

Parameters used: IPSHOW=WHAT(1)

This card determines whether hard partons initiate showers and is only recognized in connection with JETSET fragmentation. As the BAMJET option presently contains no parton showering it does not reproduce the p_{\perp} -distribution as well as the JETSET option.

IPSHOW (with JETSET)		
	= 0 :	Generation of hard parton showers suppressed.
	= 1 :	Hard parton showers are included.

The default is 1.

Code word: START

Parameters used: NEVNT = WHAT(1), PTLAR = WHAT(5)

Starts the sampling of hadronized events and the calculation of the standard histogram output.

NEVNT	Number of events sampled.
PTLAR	Cutoff parameter to sample only selected events.
= 0.0:	DTUJET samples without constraint on sampled events.
> 2.2:	DTUJET samples only events with at least one jet (minijet) with $p_{\perp} \geq \text{PTLAR}$, rejecting all other events.
< -0.1:	DTUJET samples only events without hard jets (minijets).

Defaults are not effective, as this card is necessary to run the program. The code word START should be used only once per run.

Code word: EVENTAPE

Parameter used: none

When this card is present, the events generated are written on an output file EVENTS.DTU. This file is written in the following format:

1. card: ‘‘This file contains events from DTUJET.’’
2. card: The title of the input file is reproduced.
3. card: NHAD using FORMAT(I10)
4. to 3+ NHAD -th card: I, NR(I), PX(I), PY(I), PZ(I), E(I)
using FORMAT (2I4, 4E 16.8)

where

NHAD	is the number of secondary particles in the event.
I and NR(I)	are a counting number and an integer label defining the kind of particle.
PX(I), PY(I), PZ(I)	are the momentum components of the secondary particles in the c.m.s. of the collision in GeV/c. The projectile is moving in positive z -direction.
E(I)	are the total energies of the secondary particles.

The codes for stable particles considered at the end are given in Table 1.

Table 1: List of the codes for stable particles used in BAMJET and DTUJET93.

1 = p	14 = π^-	98 = Ξ^-	121 = D_s^-
2 = \bar{p}	15 = K^+	99 = $\bar{\Sigma}^-$	137 = Λ_c^+
3 = e^+	16 = K^-	100 = $\bar{\Sigma}^0$	149 = $\bar{\Lambda}_c^+$
4 = e^-	17 = Λ	101 = $\bar{\Sigma}^+$	138 = Ξ_c^+
5 = ν	18 = $\bar{\Lambda}$	102 = $\bar{\Xi}^0$	139 = Ξ_c^0
6 = $\bar{\nu}$	19 = K_S^0	103 = $\bar{\Xi}^+$	150 = $\bar{\Xi}_c^+$
7 = γ	20 = Σ^-	109 = Ω^-	151 = $\bar{\Xi}_c^0$
8 = n	21 = Σ^+	115 = $\bar{\Omega}^-$	140 = Σ_c^{++}
9 = \bar{n}	22 = Σ^0	116 = D^0	141 = Σ_c^+
10 = μ^+	23 = π^0	117 = D^+	142 = Σ_c^0
11 = μ^-	24 = K^0	118 = D^-	152 = $\bar{\Sigma}_c^{++}$
12 = K_L^0	25 = \bar{K}^0	119 = \bar{D}^0	153 = $\bar{\Sigma}_c^+$
13 = π^+	97 = Ξ^0	120 = D_s^+	154 = $\bar{\Sigma}_c^0$

For a list of particles known to DTUJET see the PARTICLE input card. A integer array NBOOK(NR) to convert our internal number NR below NR=25 to the particle data booklet number is provided in BLOCK DATA BOOKLT at the end of dtu93mai. This conversion is done for all the stable particles given above by the INTEGER FUNCTION MPDGHA(NR) included in the dtu93lun.f file.

Code word: STOP

Parameter used: none

Stops the running of the code.

Code word: PARTICLE

Parameter used: none

This card demands the printing of a table of all particles defined in DTUJET where the particle properties and in the case of unstable particles all decay channels defined in the code are listed. The particles defined in DTUJET are the ones defined in the BAMJET and DECAY hadronization codes.

At present the normal output events of DTUJET contain particles which do not decay through hadronic interactions (most of them with number labels below $NR = 26$). This selection can be changed by modifying the defaults in the `SUBROUTINE DECAY` code of the `dtu93tcb.f` file (in the case of BAMJET fragmentation) and in the `dtu93lun.f` file (in the case of JETSET fragmentation).

Code word: XSECTION

Parameter used: none

This card demands a test run for the calculation of cross sections as function of energy. The test run yields

- the total cross section,
- the elastic cross section,
- the inelastic cross section,
- the hard inelastic cross section and
- the high and low mass
single and double diffractive cross sections.

It also provides scatter plots of the sampling of multi-Pomeron events at some typical energies.

Other code words as LHARD, SIGMAPOM, PARTEV etc. are available for special tasks but not relevant for the general user. The interested user is referred to the comments in the source code (in `dtu93mai.f`).

3.4. COMMON BLOCKS OF INTEREST FOR THE USER

It is possible to run the event generator within a user supplied program package. For this purpose the user needs to know how the event is stored in COMMON blocks.

The COMMON block /USER/

```
CHARACTER*8 PROJTY,TARGTY
CHARACTER*80 TITLE
COMMON /USER/TITLE,PROJTY,TARGTY,CMENER,ISTRUF
& , ISINGD,IDUBLD,SDFRAC,PTLAR
```

contains the parameters, expected to be modified by input cards. The meaning of the possible values of these parameters are described in section 3 .

The COMMON block /PARTCL/

```
PARAMETER (MXNUPA=2500)
COMMON/PARTCL/
& PARTPX(MXNUPA),PARTPY(MXNUPA),
& PARTPZ(MXNUPA),PARTPO(MXNUPA),
& NPARTY(MXNUPA),NPART
```

contains the final particles of the last generated event. The first NPART's positions in the arrays

```
PARTPX,PARTPY,PARTPZ,PARTPO,NPARTY
```

are transverse momenta, longitudinal momentum, energy and the type of the particles where

```
NPART
```

is number of particles in the event.

For how to obtain a printed list of our particle and resonance numbering (i.e. the meaning of NPARTY) see the input card PARTICLE. For a short list and for ways to convert to the particle data booklet numbers we refer to the discussion of the input card EVENTAPE. We did not use the particle data booklet numbers, as their range is too large to use them in better way than alphanumeric names.

3.5. SHORT DESCRIPTION OF IMPORTANT SUBROUTINES OF DTUJET

3.5.1 Subroutine calls for generating events

The main task of that program is to generate events. This involves the following five steps:

1. The program begins with a call to the subroutine DTPREP, which sets initial values and reads and implements the input cards.
2. After encountering the START input card the sampling of multi-Pomeron (hard and soft Pomerons) distributions is prepared by a call to PRBLM2. It calculates the probability distribution of hard and soft Pomerons and stores it in a suitable way. A call to SAMPLM then generates one basic scattering event according to this distribution. Various calls to other subroutines, which prepare other aspects of the sampling follow. After these tasks the subroutine DTPREP is eventually left to the main program.
3. In the main program the loop over events follows. Within this event loop a subroutine DTCOLL is called, which generates one complete hadronic event (see below). After the end of the loop and a short output the program returns to the beginning and continues until a STOP card is encountered.
4. Within DTCOLL a call to XPTFL (NHARD, NSEA, NVAL) generates one parton level event with NHARD hard Pomerons and NSEA soft sea Pomerons and one (=NVAL) soft valence Pomeron. It determines the energy-momentum distribution of the partons.
5. The hadronization of this parton level event is done by a call from DTCOLL to the routine HADRAV (NHAD, NSEA, NVAL, NHARD). The event generated contains NHAD particles in its final state. Depending on the parameter IHADRZ set with the HADRONIZ parameter card the BAMJET and DECAY routines or the JETSET routines are used for fragmentation.

3.5.2 Calculation of total and inelastic cross sections and hard and soft Pomeron distributions via the unitarization of soft and hard input cross sections

The code word XSECTION demands a major executable task (used essentially for test purposes) which calculates absorbed cross sections in the DTU model.

When demanded by the XSECTION input card the subroutine DTPREP calls the subroutine POMDI. POMDI calls the routine SIGMAS to calculate the total and inelastic cross sections according to the model as function of energy. The input hard, soft, and triple Pomeron cross sections of a given energy are defined by a call to the subroutine SIGSHD. The output cross sections are presented as alphanumeric plots.

The sampling of multi-Pomeron (hard and soft Pomeron) distributions is prepared by a call to PRBLM2, which calculates the probability distribution for n_h hard and n_s soft Pomerons. A call to SAMPLM generates one event from this distribution. POMDI generates scatter plots in n_h and n_s for 10000 sampled events at some collision energies.

3.6. EXEMPLARY INPUT AND COMMAND FILES

In Fig. 1 we reproduce an input file which allows to run DTUJET-93. This file, where we include some possible input cards even when they do not change the default settings, will lead to the calculation of 5000 events at $\sqrt{s} = 1.8$ TeV generating standard histograms.

In Fig. 2a we list an exemplary command file used for compiling DTUJET-93 files under DEC-ULTRIX, the same is given in Fig. 2b and c for HP-UX and IBM AIX respectively. Please note, that the code, not written explicitly in DOUBLE PRECISION is transformed to DOUBLE PRECISION using the compiler option for the redefinition of the constants and D-commented ("debug"-) cards in the files.

3.7. DESCRIPTION OF THE DEFAULT SHORT OUTPUT

In the papers [9,10,11,12,13] many plots are shown which originate from the DTUJET-93 code; therefore we do not need to give explicit examples for the output of DTUJET.

After repeating the input cards the minimal output contains a table of all calculated cross sections. A table containing the average multiplicity and the average energy separated for specific particle types follows. Simple alpha numeric plots then draw the rapidity, energy fraction and multiplicity distribution.

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```

TITLE
Antiproton-Proton with diffraction, STRUCFUN 215 and JETSET fragmentation.
CMENERGY      1800.
PROJPAR
TARPAR
SINGDIFF      1.      0.      1.00
START         5000.    0.      0.      0.      2.0
STOP

```

Fig 1: DTUJET-93 sample input file.

```

f77 -c -diag -fpe2 -o0 -K -d_lines -r8 -C -V <file name>.f

```

Fig 2a: Command file for compiling DTUJET-93 Fortran files under DEC-ULTRIX.

```

f77 -c -a +e -K -D -R8 +T +R -C -V <file name>.f

```

Fig 2b: Command file for compiling DTUJET-93 Fortran files under HP-UX.

```

xlf -C -c -qsource -qdpc -D <file name>.f

```

Fig 2c: Command file for compiling DTUJET-93 Fortran files under IBM-AIX.